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(54) **POWER CONVERSION APPARATUS**

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CPC ***H02M 3/33515*** (2013.01); ***H02M 1/4208*** (2013.01); ***H02M 3/33523*** (2013.01); *Y02B 70/126* (2013.01)

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USPC 363/21.01
See application file for complete search history.

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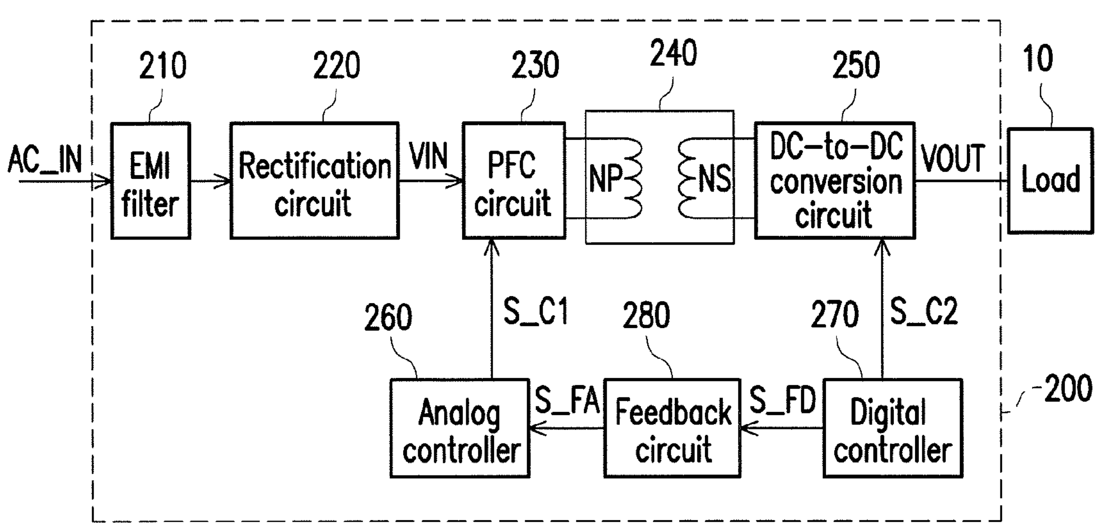
(57) **ABSTRACT**

A power conversion apparatus, including a transformer, a switch, an analog controller, a digital controller, and a voltage converter-based feedback circuit, is provided. The primary side of the transformer is coupled to an input voltage, and the secondary side of the transformer is coupled to an output voltage provided to a load. The switch intermittently transmits the input voltage to the primary side of the transformer. The analog controller is disposed at one of the primary side and the secondary side of the transformer and configured to control the operation of the switch in response to an analog feedback signal. The digital controller is disposed at the other one of the primary side and the secondary side and configured to generate a digital feedback signal. The voltage converter-based feedback circuit is configured to convert the digital feedback signal to the analog feedback signal based on a voltage conversion characteristic thereof.

10 Claims, 3 Drawing Sheets



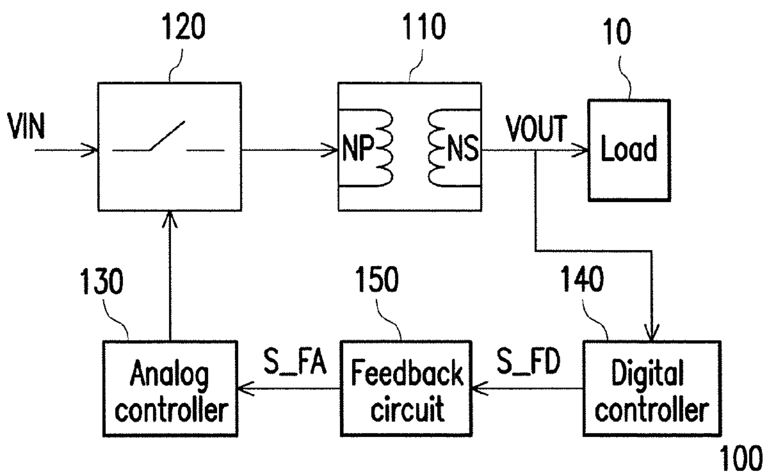

120
110
10
VIN
NP
NS
VOUT
Load
130
150
140
S_FA
S_FD
Analog controller
Feedback circuit
Digital controller
100

FIG. 1

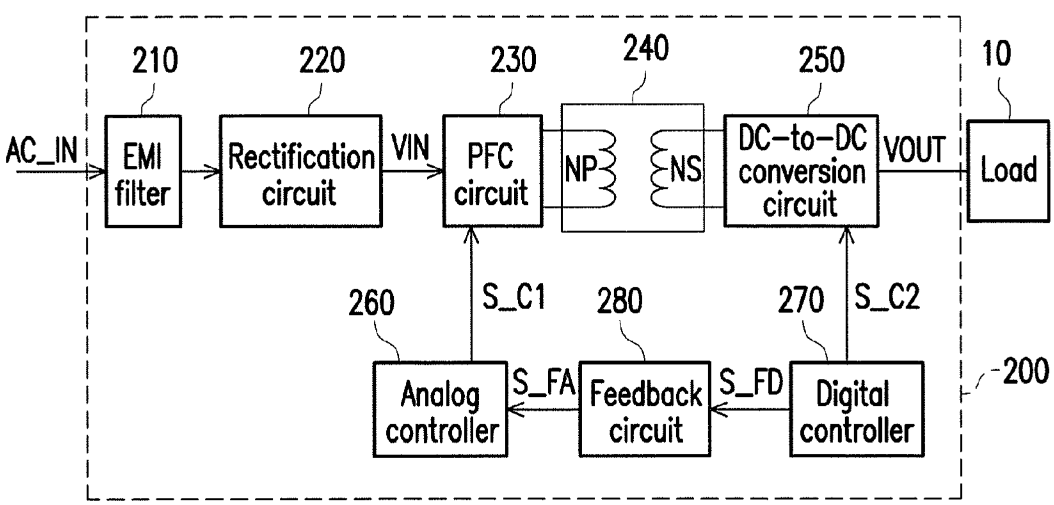

210
220
230
240
250
10
AC_IN
EMI filter
Rectification circuit
VIN
PFC circuit
NP
NS
DC-to-DC conversion circuit
VOUT
Load
260
S_C1
280
270
S_C2
S_FA
S_FD
Analog controller
Feedback circuit
Digital controller
200

FIG. 2

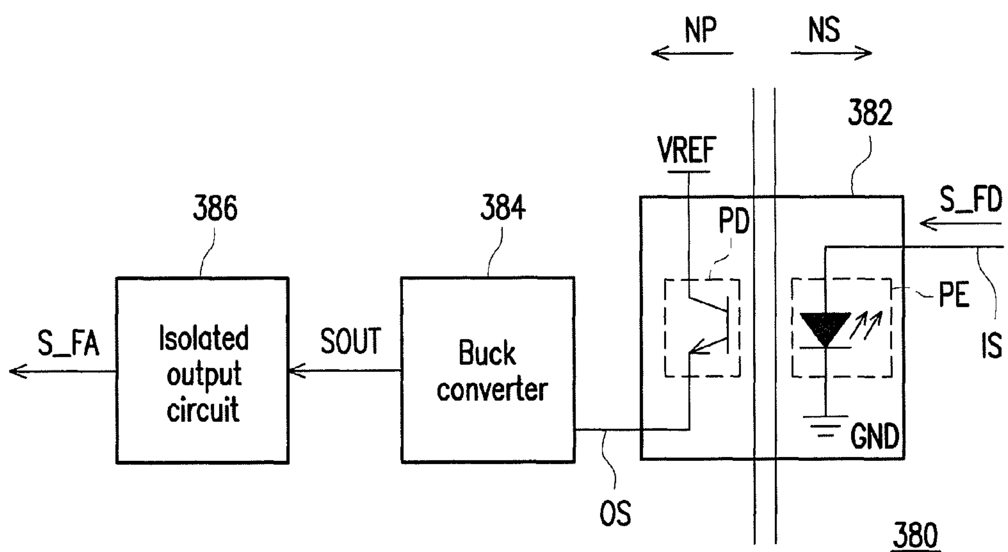

NP
NS
382
VREF
386
384
S_FD
PD
PE
S_FA
Isolated output circuit
SOUT
Buck converter
IS
GND
OS
380

FIG. 3

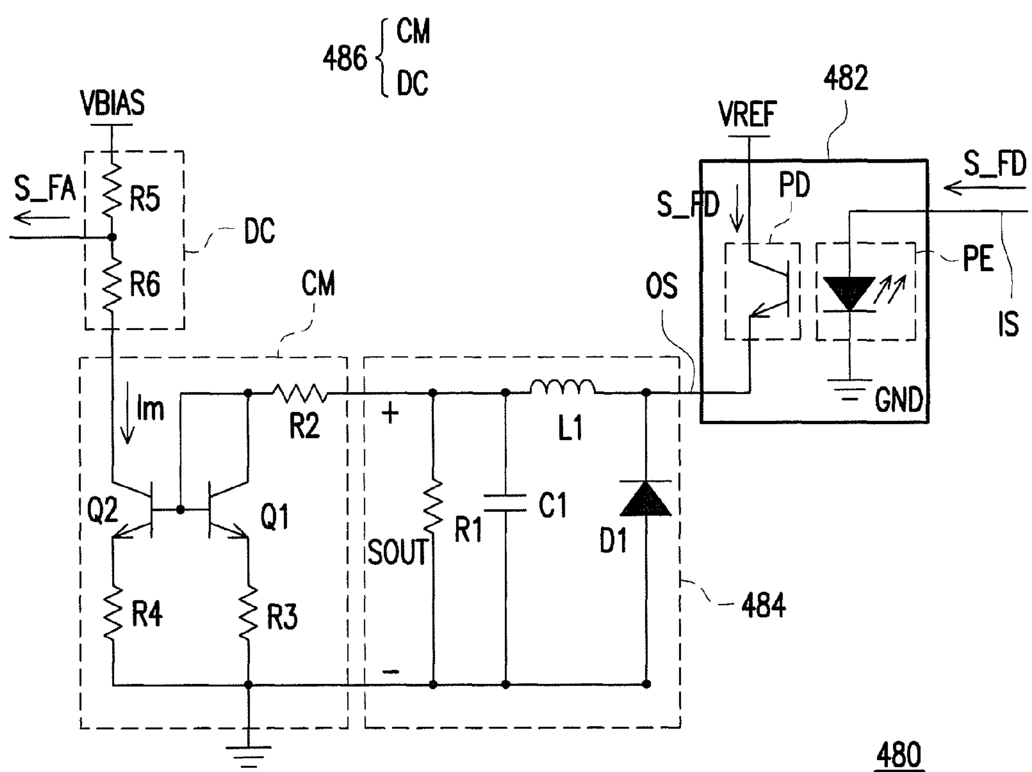

486
CM
DC
VBIAS
482
VREF
S_FA
R5
S_FD
PD
S_FD
DC
PE
R6
CM
OS
IS
Im
+
R2
L1
GND
Q2
Q1
C1
R1
D1
SOUT
R4
R3
484
-
480

FIG. 4

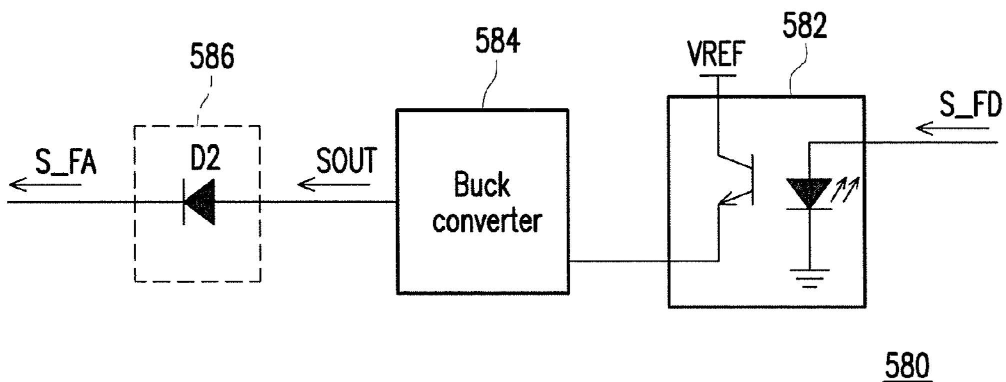

586
584
582
VREF
S_FD
S_FA
D2
SOUT
Buck converter
580

FIG. 5

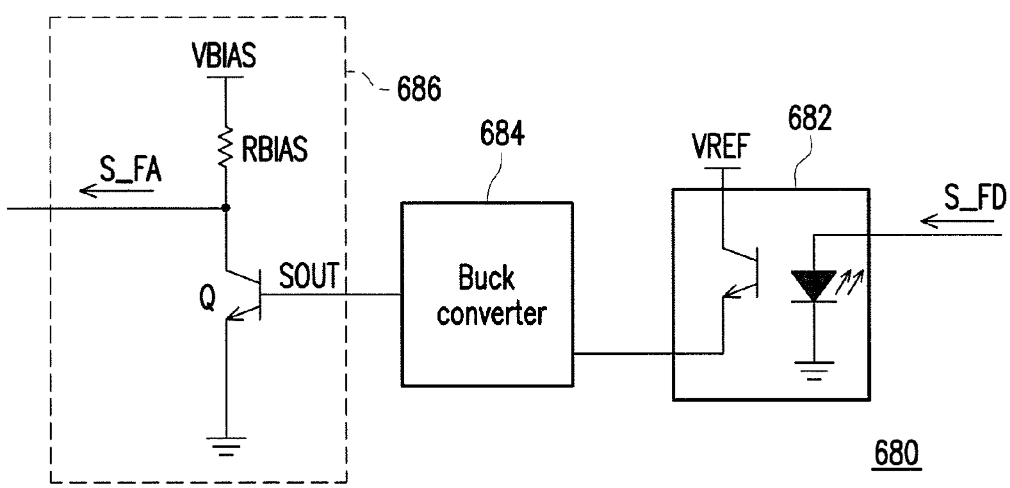

VBIAS
686
684
682
VREF
RBIAS
S_FA
S_FD
SOUT
Q
Buck converter
680

FIG. 6

POWER CONVERSION APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the priority benefit of Taiwan application serial no. 102147217, filed on Dec. 19, 2013. The entirety of the above-mentioned patent application is hereby incorporated by reference herein and made a part of this specification.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a power conversion apparatus and particularly relates to a power conversion apparatus that utilizes a voltage conversion characteristic to achieve a digital to analog conversion signal feedback mechanism.

2. Description of Related Art

Power conversion apparatuses are used mainly for converting high-voltage and lowly-stable AC input power, supplied by the power company, to low-voltage and highly-stable DC output power that is suitable for various electronic devices. Therefore, power conversion apparatuses are widely used in electronic devices, such as computers, office automation equipment, industrial control equipment, and communication equipment.

The conventional power conversion apparatus is usually provided with a power factor correction (PFC) circuit in the front-end stage for providing a constant DC input voltage (up to 380V for example) to a DC-to-DC conversion circuit in the back-end stage. No matter the power conversion apparatus is in the state of light load or heavy load, the PFC circuit provides constant high voltage (380V) to the DC-to-DC conversion circuit in the back-end stage. Thus, under the principle of constant power, power loss of the power conversion apparatus during light load increases (compared with heavy load), which lowers the overall conversion efficiency of power conversion apparatus.

In view of the above, a power conversion apparatus with a feedback control mechanism has been proposed, which allows the controller that controls the front-end stage PFC circuit to adjust the output voltage of the PFC circuit according to the operation status of the load, so as to improve the conversion efficiency. In the power conversion configuration with the feedback control mechanism, the controller that controls the back-end stage DC-to-DC conversion circuit needs to feed information associated with the operation status of the load back to the front-end stage controller.

If the back-end stage controller and the front-end stage controller are a digital circuit and an analog circuit respectively, a (chip type) digital-to-analog converter (DAC) is required to be disposed between the two controllers for performing digital to analog conversion, so as to feed the information associated with the operation status of the load from the back-end stage controller back to the front-end stage controller. However, due to limitation of the conversion characteristic of the general (chip type) digital-to-analog converter, the digital signal outputted by the back-end stage controller cannot be converted to a proportional analog signal through the digital-to-analog conversion. For this reason, an additional digital to analog converter needs to be disposed, which raises the design costs of the power conversion apparatus.

SUMMARY OF THE INVENTION

The invention provides a power conversion apparatus that achieves a digital to analog conversion signal feedback mechanism without using a (chip type) digital-to-analog converter.

The power conversion apparatus of the invention includes a transformer, a switch, an analog controller, a digital controller, and a voltage converter-based feedback circuit. The transformer has a primary side and a secondary side. The primary side of the transformer is coupled to an input voltage, and the secondary side of the transformer is coupled to an output voltage that is provided to a load. The switch is configured to intermittently transmit the input voltage to the primary side of the transformer. The analog controller is disposed at one of the primary side and the secondary side of the transformer. The analog controller is coupled to the switch and configured to control an operation of the switch in response to an analog feedback signal. The digital controller is disposed at the other one of the primary side and the secondary side of the transformer and configured to generate a digital feedback signal. The voltage converter-based feedback circuit is coupled to the analog controller and receives the digital feedback signal, and is configured to convert the digital feedback signal to the analog feedback signal according to a voltage conversion characteristic thereof.

In an embodiment of the invention, the voltage converter-based feedback circuit determines a voltage level of the analog feedback signal according to a product of a duty cycle of the digital feedback signal and a reference voltage.

In an embodiment of the invention, the voltage converter-based feedback circuit includes a photo-coupler, a voltage converter, and an isolated output circuit. The photo-coupler has an input side and an output side, wherein the input side of the photo-coupler is coupled to the digital controller to receive the digital feedback signal. The voltage converter is coupled to the output side of the photo-coupler and configured to perform a voltage conversion on the reference voltage according to the digital feedback signal coupled to the output side and generate an analog output signal accordingly. The isolated output circuit is coupled between the voltage converter and the analog controller and configured to provide the analog feedback signal to the analog controller according to the analog output signal.

In an embodiment of the invention, the voltage converter includes a first diode, an inductor, a capacitor, and a first resistor. A cathode end of the first diode is coupled to the output side and an anode end of the first diode is coupled to a ground end. A first end of the inductor is coupled to the cathode end of the first diode. A first end of the capacitor is coupled to a second end of the inductor and a second end of the capacitor is coupled to the ground end. A first end of the first resistor is coupled to the second end of the inductor and the first end of the capacitor, and a second end of the first resistor is coupled to the ground end.

In an embodiment of the invention, the isolated output circuit includes a second diode. An anode end of the second diode is coupled to an output end of the voltage converter to receive the analog output signal, and a cathode end of the second diode is coupled to the analog controller to provide the analog feedback signal.

In an embodiment of the invention, the isolated output circuit includes a bias resistor and a transistor. A first end of the bias resistor receives a bias voltage. A control end of the transistor is coupled to the output end of the voltage converter to receive the analog output signal, a first end of the transistor is coupled to the analog controller and a second end of the bias resistor to provide the analog feedback signal, and a second end of the transistor is coupled to the ground end.

In an embodiment of the invention, the isolated output circuit includes a current mirror and a dividing circuit. The current minor is coupled to the output end of the voltage converter and generates a minor current in response to the analog output signal. The dividing circuit is coupled to the current mirror to generate the analog feedback signal according to the mirror current.

In an embodiment of the invention, the minor current and a voltage level of the analog output signal have a positive correlation, and the mirror current and the voltage level of the analog feedback signal have a negative correlation.

In an embodiment of the invention, the current minor includes a second resistor, a first transistor, a second transistor, a third resistor, and a fourth resistor. A first end of the second resistor is coupled to the output end of the voltage converter. A control end and a first end of the first transistor are both coupled to a second end of the second resistor. A control end of the second transistor is coupled to the control end of the first transistor and a first end of the second transistor is coupled to the dividing circuit. A first end of the third resistor is coupled to a second end of the first transistor and a second end of the third resistor is coupled to the ground end. A first end of the fourth resistor is coupled to a second end of the second transistor and a second end of the fourth resistor is coupled to the ground end.

In an embodiment of the invention, the dividing circuit includes a fifth resistor and a sixth resistor. A first end of the fifth resistor receives a bias voltage and a second end of the fifth resistor is coupled to the analog controller. A first end of the sixth resistor is coupled to the second end of the fifth resistor and a second end of the sixth resistor is coupled to the first end of the second transistor.

In an embodiment of the invention, the power conversion apparatus further includes an electromagnetic interference filter, a rectification circuit, and a power factor correction circuit. The electromagnetic interference filter receives an AC voltage and is configured to suppress electromagnetic noise of the AC voltage. The rectification circuit is coupled to the electromagnetic interference filter and configured to rectify the AC voltage after noise suppression to generate the input voltage. The power factor correction circuit is configured to perform a power factor correction on the input voltage associated with the AC voltage, wherein the switch is disposed in the power factor correction circuit to control an operation of the power factor correction circuit.

Based on the above, the power conversion apparatus of the embodiments of the invention utilizes the voltage conversion characteristic of the feedback circuit to convert the digital feedback signal, generated by the digital controller at the secondary side and associated with the load operation status, to the analog feedback signal and provide the same to the analog controller at the primary side, such that the analog controller can control the power factor correction circuit based on the analog feedback signal. With this configuration, the digital to analog conversion of the feedback signal is achieved without using a (chip type) digital to analog converter. Therefore, the accuracy of signal feedback is effectively improved and the overall circuit configuration of the power conversion apparatus is further simplified.

To make the aforementioned and other features and advantages of the invention more comprehensible, several embodiments accompanied with drawings are described in detail as follows.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate exemplary embodiments of the invention and, together with the description, serve to explain the principles of the invention.

FIG. **1** is a schematic diagram illustrating a power conversion apparatus according to an embodiment of the invention.

FIG. **2** is a schematic diagram illustrating the power conversion apparatus according to another embodiment of the invention.

FIG. **3** is a schematic diagram illustrating a feedback circuit according to an embodiment of the invention.

FIG. **4** is a schematic diagram illustrating a circuit architecture of the feedback circuit according to an embodiment of FIG. **3**.

FIG. **5** is a schematic diagram illustrating the circuit architecture of the feedback circuit according to another embodiment of FIG. **3**.

FIG. **6** is a schematic diagram illustrating the circuit architecture of the feedback circuit according to yet another embodiment of FIG. **3**.

DESCRIPTION OF THE EMBODIMENTS

An embodiment of the invention provides a power conversion apparatus that achieves a digital to analog conversion signal feedback mechanism without using a (chip type) digital to analog converter (DAC). Thus, the accuracy of signal feedback is effectively improved and the overall circuit configuration of the power conversion apparatus is further simplified. In order to make this disclosure more comprehensible, several embodiments are described below as examples of implementation of this disclosure. Moreover, elements/components/steps with the same reference numerals are used to represent the same or similar parts in the drawings and embodiments where appropriate.

FIG. **1** is a schematic diagram illustrating a power conversion apparatus according to an embodiment of the invention. With reference to FIG. **1**, a power conversion apparatus **100** includes a transformer **110**, a switch **120**, an analog controller **130**, a digital controller **140**, and a voltage converter-based feedback circuit **150**.

The transformer **110** has a primary side NP and a secondary side NS, wherein the primary side NP of the transformer **110** is coupled to an input voltage VIN, and the secondary side NS of the transformer **110** is coupled to an output voltage VOUT that is provided to a load **10**. The switch **120** is coupled between the input voltage VIN and the transformer **110** for configuring to intermittently transmit the input voltage VIN to the primary side NP of the transformer **110** under control. The analog controller **130** is disposed at the primary side NP of the transformer **110** for configuring to control an operation of the switch **120** in response to an analog feedback signal S_FA outputted by the feedback circuit **150**. The digital controller **140** is disposed at the secondary side NS of the transformer **110** for configuring to generate a digital feedback signal S_FD associated with an operation status of the load **10** (e.g., light load, intermediate load, and heavy load). The voltage converter-based feedback circuit **150** is coupled to the analog controller **130** and receives the digital feedback signal S_FD. In addition, the feedback circuit **150** is configured to convert the digital feedback signal S_FD to the analog feedback signal S_FA according to a voltage conversion characteristic thereof.

Under the configuration of the power conversion apparatus **100** of this embodiment, the switch **120** may be a power switch included in a power factor correction (PFC) circuit or a pulse-width modulation (PWM) control circuit, for example. However, it should be noted that the invention is not limited thereto. That is to say, the voltage converter-based feedback circuit **150** of the embodiment of the invention is applicable to any power conversion apparatus that uses the configuration of the switch **120** for feedback control, so as to achieve the digital to analog conversion signal feedback mechanism without using a (chip type) digital to analog converter.

Moreover, although the analog controller **130** is disposed at the primary side NP of the transformer **110** while the digital controller **140** is disposed at the secondary side NS of the transformer **110** in this embodiment, the invention is not limited thereto. In another exemplary embodiment, the analog controller **130** and the digital controller **140** may be respectively disposed at the secondary side NS and the primary side NP of the transformer **110** according to the requirements of circuit design. In other words, the analog controller **130** of this embodiment may be disposed at one of the primary side NP and the secondary side NS of the transformer **110**, and the digital controller **140** may be disposed at the other one of the primary side NP and the secondary side NS of the transformer **110**.

Below a specific configuration of the power conversion apparatus of the embodiment of FIG. **1** is described with reference to FIG. **2** as an example. FIG. **2** is a schematic diagram illustrating the power conversion apparatus according to another embodiment of the invention. With reference to FIG. **2**, a power conversion apparatus **200** includes an electromagnetic interference filter (EMI filter) **210**, a rectification circuit **220**, a power factor correction circuit **230**, a transformer **240**, a DC-to-DC conversion circuit **250**, an analog controller **260**, a digital controller **270**, and a voltage converter-based feedback circuit **280**.

In this embodiment, the electromagnetic interference filter **210** receives an AC voltage AC_IN (e.g., mains supply or city power, but not limited thereto) and is configured to suppress electromagnetic noise of the AC voltage AC_IN; and the rectification circuit **220** is configured to receive the AC voltage AC_IN after noise suppression and rectify the AC voltage AC_IN to generate the input voltage VIN.

An input end of the power factor correction circuit **230** is coupled to the rectification circuit **220** for configuring to perform power factor correction on the input voltage VIN associated with the AC voltage AC_IN and provide the input voltage after power factor correction to the primary side NP of the transformer **240**. The transformer **240** induces a corresponding voltage at the secondary side NS based on the voltage at the primary side NP (i.e., the input voltage VIN after power factor correction) and provides the induced voltage to the DC-to-DC conversion circuit **250**. The DC-to-DC conversion circuit **250** performs power conversion (e.g., buck conversion, boost conversion, or buck-boost conversion, but not limited thereto) in response to the voltage induced at the secondary side NS of the transformer **240**, so as to generate the DC output voltage VOUT to be used by the load **10**.

More specifically, operations of the power factor correction circuit **230** and the DC-to-DC conversion circuit **250** are respectively controlled by control signals S_C**1** and S_C**2** provided by the analog controller **260** and the digital controller **270** respectively. In addition to controlling the operation of the DC-to-DC conversion circuit **250**, the digital controller **270** further detects the operation status of the load **10** and provides operation status information of the load **10** to the analog controller **260** through the feedback circuit **280** coupled between the digital controller **270** and the analog controller **260**, such that the analog controller **260** adjusts the provided control signal S_C**1** accordingly to adjust the output of the power factor correction circuit **230** in response to the operation status of the load **10**. Here, the control signals S_C**1** and S_C**2** may be pulse-width modulation control signals, for example, wherein the analog controller **260** and the digital controller **270** adjust duty cycles of the control signals

S_C**1** and S_C**2** to control the ON/OFF states of switches (not shown; e.g., **120**) disposed in the power factor correction circuit **230** and the DC-to-DC conversion circuit **250**, thereby adjusting the outputs of the power factor correction circuit **230** and the DC-to-DC conversion circuit **250** correspondingly.

In this embodiment, the digital controller **270** sends the digital feedback signal S_FD that indicates the operation status of the load **10** back to the voltage converter-based feedback circuit **280**, such that the feedback circuit **280** converts the digital feedback signal S_FD received from the digital controller **270** to the analog feedback signal S_FA according to the voltage conversion characteristic thereof (i.e., the output voltage is equal to a product of the duty cycle and the input voltage) and provides the analog feedback signal S_FA to the analog controller **260** to serve as a basis for controlling the power factor correction circuit **230**.

More specifically, the voltage converter-based feedback circuit **280** of this embodiment uses the digital feedback signal S_FD as the control signal of a power switch thereof (not shown; a specific configuration thereof is explained in the subsequent embodiment), so as to perform voltage conversion on a reference voltage in response to the digital feedback signal S_FD.

Take a buck converting voltage converter as an example (i.e., buck converter, but the invention is not limited thereto), because of the characteristic that the output voltage of the buck converter has a voltage level which is equal to a voltage level of the input voltage (i.e., the reference voltage) multiplied by the duty cycle of the control signal (i.e., the digital feedback signal S_FD) ($Vout=Duty\times Vin$, wherein Vout: output voltage, Duty: duty cycle, and Vin: input voltage), if the reference voltage is a fixed value, the voltage level of the analog feedback signal S_FA generated by the feedback circuit **280** has a specific relationship with the duty cycle of the digital feedback signal S_FD. That is, in this embodiment, the voltage converter-based feedback circuit **280** determines the voltage level of the analog feedback signal S_FA according to the product of the duty cycle of the digital feedback signal S_FD and the reference voltage.

Thus, with the design of the voltage converter-based feedback circuit **280**, the power conversion apparatus **200** of this embodiment is capable of converting the digital feedback signal S_FD that indicates the operation status of the load **10** to the analog feedback signal S_FA without using a (chip type) digital to analog converter. In comparison with the conventional power conversion configuration that uses a (chip type) digital to analog converter as the feedback circuit, the feedback circuit **280** of this embodiment achieves the function of digital to analog conversion without the (chip type) digital to analog converter and thus effectively reduces the design complexity thereof. With the digital to analog conversion of the feedback circuit **280**, because the duty cycle of the digital feedback signal S_FD is converted to the voltage level of the analog feedback signal S_FA in the same proportion, there is less distortion in comparison with the case of using a general (chip type) digital to analog converter. In other words, the analog feedback signal S_FA indicates the operation status of the load **10** more accurately.

In order to more clearly explain the specific configuration and operation of the feedback circuit according to the embodiment of the invention, FIG. **3** illustrates a feedback circuit **380** as an example below. FIG. **3** is a schematic diagram illustrating a feedback circuit according to an embodiment of the invention.

With reference to FIG. **3**, in this embodiment, the voltage converter-based feedback circuit **380** includes a photo-coupler **382**, a voltage converter **384** (which is also a buck converter, for example), and an isolated output circuit **386**. The photo-coupler **382** has an input side IS and an output side OS, wherein the input side IS of the photo-coupler **382** is coupled to the digital controller (e.g., **140** or **270**) at the secondary side NS to receive the digital feedback signal S_FD. The voltage converter **384** is coupled to the output side OS of the photo-coupler **382** for configuring to perform voltage conversion (referring to buck conversion here) on a reference voltage VREF according to the digital feedback signal S_FD coupled to the output side OS and generate an analog output signal SOUT accordingly. The isolated output circuit **386** is coupled between the voltage converter **384** and the analog controller (e.g., **130** or **260**) at the primary side NP and configured to provide the analog feedback signal S_FA to the analog controller according to the analog output signal SOUT received from the voltage converter **384**.

To be more specific, the photo-coupler **382** includes a light emitting device PE and a light detecting device PD, wherein the light emitting device PE emits a corresponding light signal in response to the digital feedback signal S_FD, and the light detecting device PD detects the light signal emitted by the light emitting device PE and converts the light signal to a corresponding electrical signal. In this embodiment, an end of the light detecting device PD receives the reference voltage VREF and the other end of the light detecting device PD is coupled to the input end of the voltage converter **384**. The light detecting device PD is turned on or off in response to the light signal associated with the digital feedback signal S_FD, so as to provide the reference voltage VREF to the voltage converter **384** in a switchable/intermittent manner.

It is known from the above that, in this embodiment, the light detecting device PD of the photo-coupler **382** is deemed as the power switch of the voltage converter **384**, wherein a resonant circuit (not shown) in the voltage converter **384** is charged/discharged in response to the state of the light detecting device PD (controlled by the digital feedback signal S_FD for turning on or off), so as to perform the operation of voltage conversion/buck conversion on the reference voltage VREF.

That is, for the voltage converter **384**, the input voltage (Vin) is equivalent to the reference voltage VREF, and the control signal of the voltage conversion/buck conversion is equivalent to the digital feedback signal S_FD. Therefore, the voltage level of the analog output signal SOUT generated by the voltage converter **384** is determined according to the reference voltage VREF and the duty cycle of the digital feedback signal S_FD, which conforms to the characteristic of $Vout=Duty\times Vin$.

Below FIG. **4** to FIG. **6** further illustrate specific embodiments of the feedback circuit of the invention.

First, with reference to FIG. **4**, FIG. **4** is a schematic diagram illustrating a circuit architecture of the feedback circuit according to an embodiment of FIG. **3**. In this embodiment, a feedback circuit **480** includes a photo-coupler **482**, a voltage converter **484**, and an isolated output circuit **486**.

The photo-coupler **482** receives the digital feedback signal S_FD from the digital controller (e.g., **140** or **270**) through the input side IS (an anode end of the light emitting device PE) and provides the reference voltage VREF to the voltage converter **484** through the output side OS in response to the digital feedback signal S_FD in a switchable manner.

Here, the voltage converter **484** has a buck conversion circuit configuration, composed of a diode D**1**, an inductor L**1**, a capacitor C**1**, and a resistor R**1**, for example (however, the invention is not limited thereto; and a voltage converter having other circuit topology structures (including buck conversion, boost conversion, or buck-boost conversion) is also applicable). A cathode end of the diode D**1** is coupled to the second end of the light detecting device PD and an anode end of the diode D**1** is coupled to a ground end GND. A first end of the inductor L**1** is coupled to the cathode end of the diode D**1**. A first end of the capacitor C**1** is coupled to a second end of the inductor L**1** and a second end of the capacitor C**1** is coupled to the ground end GND. A first end of the resistor R**1** is coupled to the second end of the inductor L**1** and the first end of the capacitor C**1**, and a second end of the resistor R**1** is coupled to the ground end GND. With this configuration, the inductor L**1** and the capacitor C**1** constitute a resonant tank and perform a charging/discharging operation in response to the reference voltage VREF that is outputted in a switchable manner, so as to establish an output voltage (i.e., the analog output signal SOUT) at two ends of the capacitor C**1** and the resistor R**1**.

The isolated output circuit **486** includes a current mirror CM and a dividing circuit DC, wherein the current mirror CM is coupled to the output end of the voltage converter **484** and generates a mirror current Im in response to the analog output signal SOUT outputted by the voltage converter **484**; and the dividing circuit DC is coupled to the current mirror CM to generate the analog feedback signal S_FA according to the mirror current Im.

In this embodiment, the current mirror CM has a circuit configuration composed of resistors R**2**-R**4** and transistors Q**1** and Q**2**, for example (however, the invention is not limited thereto, and a current mirror circuit having other circuit topology structures is also applicable). Here, the transistors Q**1** and Q**2** are npn type bipolar junction transistors (BJTs), for example. However, the transistors Q**1** and Q**2** may also be implemented by using pnp type BJTs or MOS transistors. Nevertheless, the invention is not limited to the above. Moreover, the dividing circuit DC has a circuit configuration composed of resistors R**5** and R**6**, for example (the invention is not limited thereto, either).

More specifically, in the current mirror CM, a first end of the resistor R**2** is coupled to the output end of the voltage converter **484** (a common node of the capacitor C**1**, the inductor L**1**, and the resistor R**1**). A base and a collector of the transistor Q**1** are coupled to a second end of the resistor R**2**. A base of the transistor Q**2** is coupled to the base of the transistor Q**1**. First ends of the resistors R**3** and R**4** are respectively coupled to emitters of the transistors Q**1** and Q**2**, and second ends of the resistors R**3** and R**4** are coupled to the ground end GND.

In the dividing circuit DC, a first end of the resistor R**5** receives a bias voltage VBIAS, and a second end of the resistor R**5** is coupled to the analog controller. A first end of the resistor R**6** is coupled to the second end of the resistor R**5**, and a second end of the resistor R**6** is coupled to a collector of the transistor Q**2**.

Based on the aforementioned circuit configuration, the current mirror CM generates the corresponding mirror current Im in response to the analog output signal SOUT, such that the dividing circuit DC generates the analog feedback signal S_FA on a dividing point thereof (a common node of the resistors R**5** and R**6**) based on the mirror current Im.

To be more specific, with the configuration of the current mirror CM, the mirror current Im has a positive correlation with the voltage level of the analog output signal SOUT outputted by the voltage converter **484**. That is, as the voltage level of the analog output signal SOUT increases, the mirror current Im increases. On the other hand, the bias voltage VBIAS received by the dividing circuit DC is a fixed voltage. Therefore, the voltage on the dividing point of the dividing circuit DC has a negative correlation with the mirror current Im. That is, as the mirror current Im increases, the voltage on the dividing point decreases (because the increase of the mirror current Im increases the voltage drop caused by the resistor R**5**). In other words, the mirror current Im and the voltage level of the analog feedback signal S_FA have a negative correlation. As a result, the voltage level variation between the analog output signal SOUT and the analog feedback signal S_FA also shows a negative correlation.

It is known from the above that, in this embodiment, as the duty cycle of the digital feedback signal S_FD increases, the voltage level of the analog output signal SOUT outputted by the voltage converter **484** decreases. Thus, the duty cycle of the digital feedback signal S_FD and the voltage level of the analog feedback signal S_FA have a positive relationship/positive correlation.

With reference to FIG. **5**, FIG. **5** is a schematic diagram illustrating the circuit architecture of the feedback circuit according to another embodiment of FIG. **3**. In this embodiment, a feedback circuit **580** also includes a photo-coupler **582**, a voltage converter **584**, and an isolated output circuit **586**, wherein the overall configuration and operation of the photo-coupler **582** and the voltage converter **584** are the same as those specified in the embodiment of FIG. **3** and thus are not repeated hereinafter.

More specifically, a main difference between this embodiment and the embodiment of FIG. **4** lies in that the circuit configuration of the isolated output circuit **586** is implemented using a diode D**2**. An anode end of the diode D**2** is coupled to the output end of the voltage converter **584** to receive the analog output signal SOUT, and a cathode end of the diode D**2** is coupled to the analog controller to provide the analog feedback signal S_FA. Accordingly, the isolated output circuit **586** of this embodiment uses the analog output signal SOUT as the analog feedback signal S_FA, wherein the diode D**2** is mainly used for isolating the analog controller and the voltage converter **584**, so as to prevent the analog controller from causing any unexpected influence to the voltage conversion operation of the voltage converter **584**.

With reference to FIG. **6**, FIG. **6** is a schematic diagram illustrating the circuit architecture of the feedback circuit according to yet another embodiment of FIG. **3**. In this embodiment, a feedback circuit **680** also includes a photo-coupler **682**, a voltage converter **684**, and an isolated output circuit **686**, wherein the overall configuration and operation of the photo-coupler **682** and the voltage converter **684** are the same as those specified in the embodiment of FIG. **4** and thus are not repeated hereinafter.

More specifically, a main difference between this embodiment and the embodiment of FIG. **4** or FIG. **5** lies in that the circuit configuration of the isolated output circuit **686** is implemented by a configuration composed of a bias resistor RBIAS and a transistor Q. A first end of the bias resistor RBIAS receives the bias voltage VBIAS. A base of the transistor Q is coupled to the output end of the voltage converter **684** to receive the analog output signal SOUT, a collector of the transistor Q is coupled to the analog controller and a second end of the bias resistor RBIAS to provide the analog feedback signal S_FA, and an emitter of the transistor Q is coupled to the ground end GND. Accordingly, the transistor Q changes the degree of conduction thereof according to the voltage level of the analog output signal SOUT and thereby generates a corresponding bias current, so as to cause the bias resistor RBIAS to generate the corresponding voltage drop and establish the analog feedback signal S_FA at the collector of the transistor Q. It is worth mentioning that, although the transistor Q of this embodiment is an npn type BJT, for example, the transistor Q may also be implemented by using a pnp type BJT or a MOS transistor. Nevertheless, the invention is not limited thereto.

In conclusion, the power conversion apparatus provided by the embodiments of the invention utilizes the voltage conversion characteristic of the feedback circuit to convert the digital feedback signal, generated by the digital controller at the secondary side and associated with the load operation status, to the corresponding analog feedback signal and provide the same to the analog controller at the primary side, such that the analog controller can control the power factor correction circuit based on the analog feedback signal. With this configuration, the digital to analog conversion of the feedback signal is achieved without using a (chip type) digital to analog converter. Therefore, the accuracy of signal feedback is effectively improved and the overall circuit configuration of the power conversion apparatus is further simplified.

It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed embodiments without departing from the scope or spirit of the disclosure. In view of the foregoing, it is intended that the disclosure covers modifications and variations provided that they fall within the scope of the following claims and their equivalents.

What is claimed is:

1. A power conversion apparatus, comprising:
- a transformer comprising a primary side and a secondary side, wherein the primary side is coupled to an input voltage and the secondary side is coupled to an output voltage that is provided to a load;
- a switch configured to intermittently transmit the input voltage to the primary side;
- an analog controller disposed at one of the primary side and the secondary side and coupled to the switch to control an operation of the switch in response to an analog feedback signal;
- a digital controller disposed at the other one of the primary side and the secondary side and configured to generate a digital feedback signal;
- a voltage converter-based feedback circuit coupled to the analog controller and having a voltage conversion characteristic, wherein the voltage converter-based feedback circuit receives the digital feedback signal and converts the digital feedback signal to the analog feedback signal according to the voltage conversion characteristic;
- an electromagnetic interference filter receiving an AC voltage and configured to suppress electromagnetic noise of the AC voltage;
- a rectification circuit coupled to the electromagnetic interference filter and configured to rectify the AC voltage after noise suppression to generate the input voltage; and
- a power factor correction circuit configured to perform a power factor correction on the input voltage associated with the AC voltage, wherein the switch is disposed in the power factor correction circuit to control an operation of the power factor correction circuit.

2. The power conversion apparatus according to claim **1**, wherein the voltage converter-based feedback circuit determines a voltage level of the analog feedback signal according to a product of a duty cycle of the digital feedback signal and a reference voltage.

3. The power conversion apparatus according to claim 1, wherein the voltage converter-based feedback circuit comprises:

a photo-coupler comprising an input side and an output side, wherein the input side is coupled to the digital controller to receive the digital feedback signal;

a voltage converter coupled to the output side to perform a voltage conversion on a reference voltage according to the digital feedback signal coupled to the output side and generate an analog output signal accordingly; and

an isolated output circuit coupled between the voltage converter and the analog controller to provide the analog feedback signal to the analog controller according to the analog output signal.

4. The power conversion apparatus according to claim 3, wherein the voltage converter comprises:

a first diode comprising a cathode end and an anode end, wherein the cathode end of the first diode is coupled to the output side and the anode end of the first diode is coupled to a ground end;

an inductor comprising a first end coupled to the cathode end of the first diode;

a capacitor comprising a first end and a second end, wherein the first end of the capacitor is coupled to a second end of the inductor and the second end of the capacitor is coupled to the ground end; and

a first resistor comprising a first end and a second end, wherein the first end of the first resistor is coupled to the second end of the inductor and the first end of the capacitor, and the second end of the first resistor is coupled to the ground end.

5. The power conversion apparatus according to claim 3, wherein the isolated output circuit comprises:

a second diode comprising an anode end and a cathode end, wherein the anode end of the second diode is coupled to an output end of the voltage converter to receive the analog output signal, and the cathode end of the second diode is coupled to the analog controller to provide the analog feedback signal.

6. The power conversion apparatus according to claim 3, wherein the isolated output circuit comprises:

a bias resistor comprising a first end to receive a bias voltage; and

a transistor comprising a control end, a first end and a second end, wherein the control end of the transistor coupled to the output end of the voltage converter to receive the analog output signal, a first end of the transistor coupled to the analog controller and a second end of the bias resistor to provide the analog feedback signal, and a second end of the transistor coupled to a ground end.

7. The power conversion apparatus according to claim 3, wherein the isolated output circuit comprises:

a current mirror coupled to the output end of the voltage converter and generating a mirror current in response to the analog output signal; and

a dividing circuit coupled to the current mirror to generate the analog feedback signal according to the mirror current.

8. The power conversion apparatus according to claim 7, wherein the mirror current and a voltage level of the analog output signal have a positive correlation, and the mirror current and a voltage level of the analog feedback signal have a negative correlation.

9. The power conversion apparatus according to claim 7, wherein the current mirror comprises:

a second resistor comprising a first end coupled to the output end of the voltage converter;

a first transistor comprising a control end and a first end both coupled to a second end of the second resistor;

a second transistor comprising a control end and a first end, wherein the control end of the second transistor is coupled to the control end of the first transistor and the first end of the second transistor is coupled to the dividing circuit;

a third resistor comprising a first end and a second end, wherein the first end of the third resistor is coupled to a second end of the first transistor and the second end of the third resistor is coupled to a ground end; and

a fourth resistor comprising a first end and a second end, wherein the first end of the fourth resistor is coupled to a second end of the second transistor and the second end of the fourth resistor is coupled to the ground end.

10. The power conversion apparatus according to claim 9, wherein the dividing circuit comprises:

a fifth resistor comprising a first end and a second end, wherein the first end of the fifth resistor receives a bias voltage and the second end of the fifth resistor is coupled to the analog controller; and

a sixth resistor comprising a first end and a second end, wherein the first end of the sixth resistor is coupled to the second end of the fifth resistor and the second end of the sixth resistor is coupled to the first end of the second transistor.

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